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REAL-TIME THERMAL NEUTRON RADIOGRAPHIC DETECTION SYSTEMS

SYSTEME DE DETECTION POUR RADIOSCOPIE PAR LES NEUTRONS THERMIQUES

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SUMMARY: Systems for real-time detection of thermal neutron images are reviewed. Characteristics of one system are presented; the data include contrast, resolution and speed of response over the thermal neutron intensity range 2.5×10^{3} n/cm^{2}-sec to 10^{7} n/cm^{2}-sec.

RESUME : On effectue une revue des differents systems de detection pour la radioscopie par les neutrons thermiques. On presente les caracteristiques d' un de ces systemes; les donnees comprennent le contraste, la resolution et le temps de reponse pour differentes intensites de neutrons thermiques de $2{,}5.10^{3}$ n/cm^{2}.s ā 10^{7} n/cm^{2}.s.

I. INTRODUCTION

Techniques for converting thermal neutron images into visible light to provide real-time, remote-viewing detection capability have been described by several investigators[1-8]. The techniques have involved direct observation of the resultant light with television cameras[5,7], the use of image intensifier tubes to detect the light from an external neutron scintillator[6,8], and the use of an integral image intensifier tube containing the neutron scintillator[1-4]. A television camera provided remote viewing of images in each case. Applications have included observations of nuclear fuel[9], a water-steel heat pipe[10], explosives[11,12] and real-time neutron diffraction[13]. Some real-time observations of neutrons in the epithermal energy range have been reported[14] and a brief description of a real-time neutron radiography system for field use with californium radioactive neutron sources has also been given.[15]

Most of these previous reports described the characteristics of the radiographic system with a particular neutron intensity. This report differs in that a number of detection system characteristics, namely high contrast resolution, contrast for both hydrogenous material and metal behind steel, and system speed of response are given for several different thermal neutron intensities covering a range from 2.5×10^{3} n/cm$^{2}\cdot$sec to about 10^{7} n/cm$^{2}\cdot$sec. Therefore, organizations having a neutron source intensity within the range covered can quickly determine the detector characteristics they could expect to achieve.

This type of information may encourage the use of remote viewing systems for neutron radiography. Useful real-time radiographic results without integration longer than 1/30 second appear to be feasible for neutron intensities down to about 10^{5} n/cm$^{2}\cdot$sec. Below that intensity (and in some cases above it), integration of the signal beyond the normal television frame time (by electronic or photographic methods) will probably be necessary to achieve useful results except for gross inspections (to observe "O" rings, for example). The range of neutron intensities covered includes those that can be available from all types of neutron sources, namely reactor, accelerator, radioactive and subcritical assemblies.

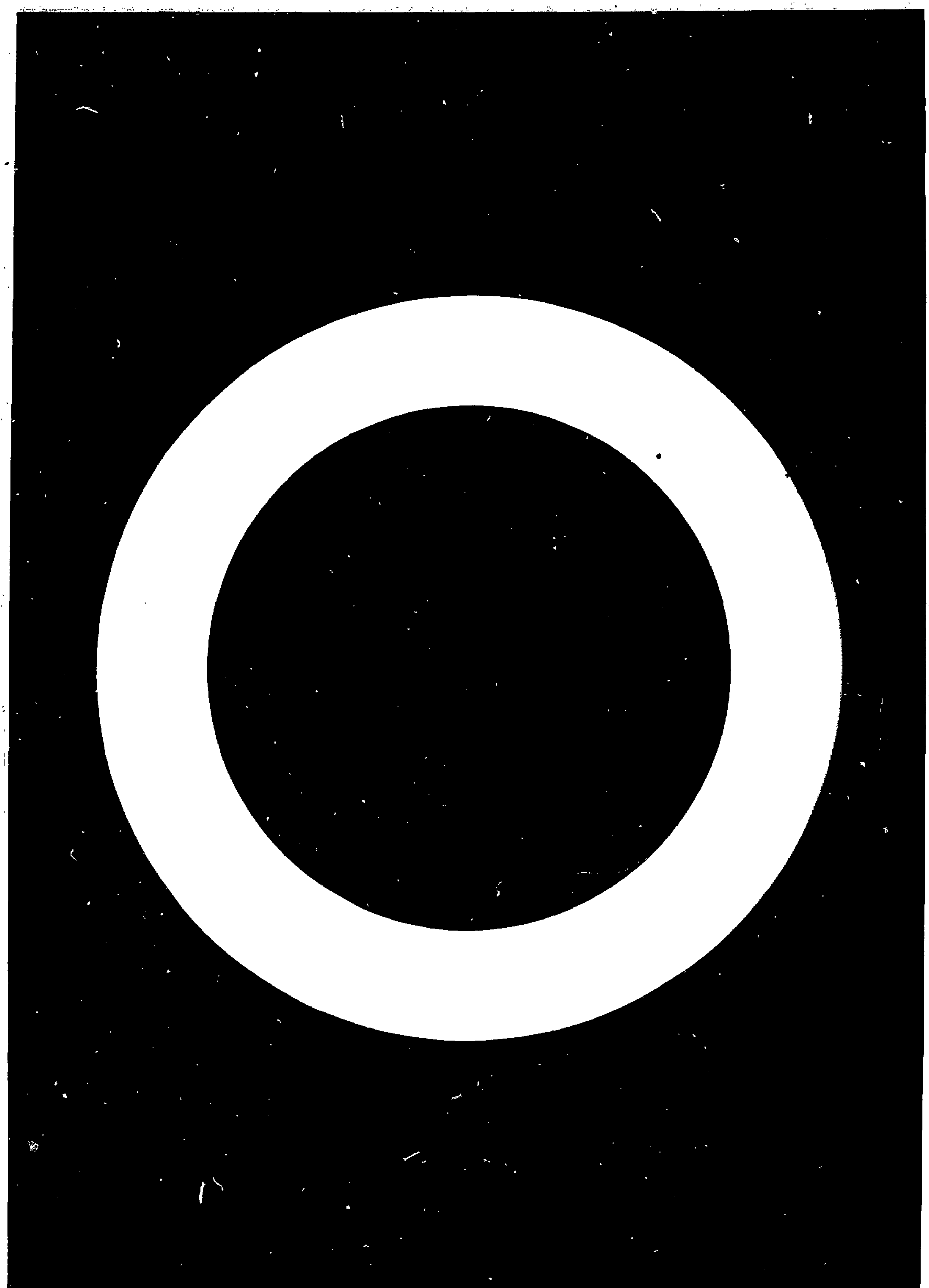

Table I. Contrast and Speed Response of Real-Time System to Various Neutron Intensities

Thermal Neutron Intensity(a) n/cm^2.sec	CONTRAST (b) On 6.35 mm Steel Thickness	2T Hole Step	On 12.7 mm Steel Thickness	2T Hole Step	On 25.4 mm Steel Thickness	2T Hole Step	Speed of Response (c) m/min	Beam Characteristics Gamma Intensity R/hr(d)	Neutron to Gamma Ratio n/cm^2-mR
	mm	mm	mm	mm	mm	mm			
6×10^6	Pl 0.375	0.5	Pl 0.375	0.5	Pl 1	1.5	2	15	10^6
	Fe 0.5	1	Fe 1	2	Fe 2	-			
1.3×10^6	Pl 0.375	0.75	Pl 0.5	0.75	Pl 1	2	1.8	5	9×10^5
	Fe 0.75	1.5	Fe 1.5	2	Fe -	-			
2.6×10^5	Pl 0.375	1	Pl 0.5	1.5	Pl 1	-	0.5	1.8	5×10^5
	Fe 1	-	Fe 1.5	-	Fe -	-			
6×10^4	Pl 0.5	1.5	Pl 1	-			Any motion blurs cadmium image	0.6	3.6×10^5
	Fe 2	-	Fe 2	-	-	-			
1.6×10^4	None detectable		-	-	-	-	" "	0.5	1.2×10^5
2.5×10^3	None detectable		-	-	-	-	" "	0.075	1.2×10^5

Notes to Table I

(a) Intensities lower than 10^6n/cm^2-sec were obtained by adding cadmium filters to the beam.

(b) Thicknesses of plastic (Pl) and steel (Fe) observable are given in mm in the first column. Also given is the step thickness T for the smallest 2T hole diameter that could be observed on each stepped wedge.

(c) Fastest motion that does not blur image of 2 mm hole in cadmium is given. The fastest speed available for the test was 2 m/min.

(d) Gamma intensity was measured with a Victoreen Model 444 survey meter.

Table II. Resolution Obtained With Real-Time Neutron Radiography

Thermal Neutron Intensity $n/cm^2.sec$	Spatial Resolution[a] (mm)			
	No Absorber	6.35 mm Steel	12.7 mm Steel	25.4 mm Steel
$6x10^6$	0.5	0.5	1	1
$1.3x10^6$	0.5	0.5	1	1.5
$2.6x10^5$	0.5	1	1	>2
$6x10^4$	1	1.5	2	>2
$1.6x10^4$	>2			
$2.5x10^3$	>2			

Note: a. Hole size in cadmium test piece (Fig. 3) observable with various absorbers in the beam path.

IV. CONCLUSIONS

At thermal neutron intensities of $10^6 n/cm^2$-sec or higher it was possible to observe high contrast detail as small as 0.5 mm in real-time in the unattenuated beam and detail of 1 mm through beams containing steel up to 12.7 mm thick. Detail of 1.5 mm could be observed through 25.4 mm of steel for the higher neutron intensities. As the neutron intensity decreased to $6x10^4 n/cm^2$-sec, detail as small as 2 mm could still be observed through 12.7 mm steel.

Contrast capability at the highest intensity ($6x10^6 n/cm^2$-sec) permitted real-time observation of 0.375 mm plastic through 12.7 mm steel. For steel, the thickness variation that could be observed was 8%. At intensities as low as $6x10^4 n/cm^2$-sec, the steel thickness variation detectable increased to about 12%. For intensities less than that, contrast capability degraded appreciably for real-time observation. Also the motion capability of the real-time system caused blurring of any object movement.

This information indicates that useful resolution and contrast can be obtained with real-time observation in thermal neutron intensities about $10^5 n/cm^2$-sec or higher. Below that intensity the performance of the system is marginal and will probably provide useful inspection results only with integration methods to accumulate better image statistics. This can include electronic storage systems, photographic integration by time exposure from the monitor, or something as simple as a high persistence detection or viewing screen.

Tests with electronic integration systems have shown useful test results for thermal neutron intensities in the order of $10^3 n/cm^2$-sec.

V. ACKNOWLEDGMENTS

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VI. REFERENCES AND FOOTNOTES

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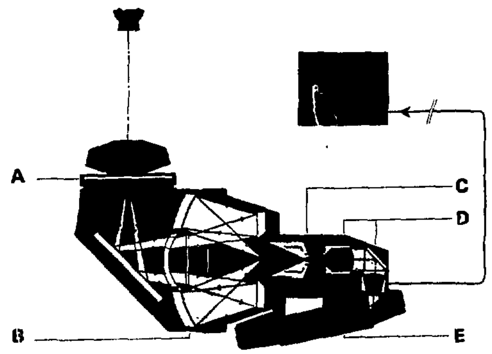

Figure 1: A diagram of the real-time system used for the imaging tests. A. is the fluorescent screen, B. and D. the optics, C. the light image intensifier: and E., the Isocon television camera.

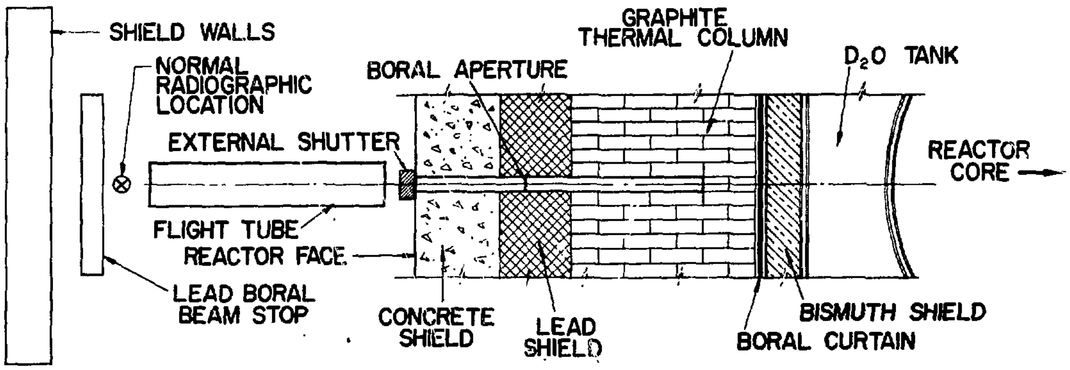

Figure 2: A diagram of the neutron radiographic facility at the NBS Reactor thermal column.

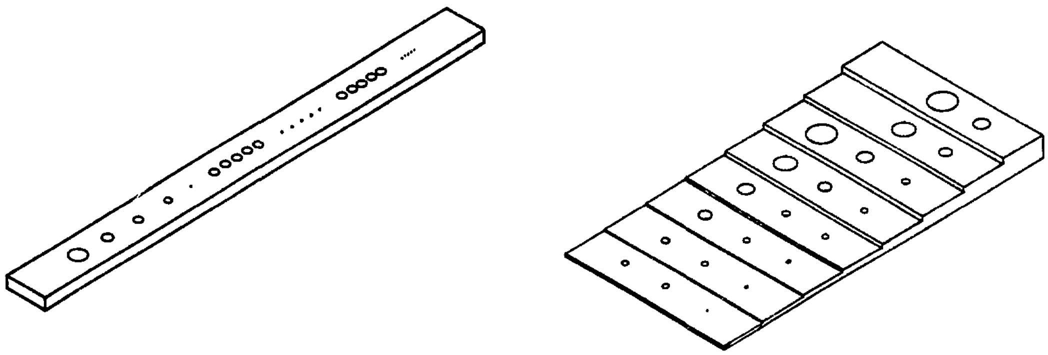

Figure 3: Diagrams of the two test piece configurations used. The cadmium test strip (left) contains series of holes as small as 0.25 mm in diameter and separation. The stepped wedge (two were used, one made of plastic and one of steel) varied in thickness from 0.125 to 2 mm. The test pieces are described in Section III.